PFM5 Calibration File
Notes on Load Curve Analysis

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Abstract

A summary on the load curve analysis for data obtained from PFM5 is given, including the procedure, the conversion of the data from raw units and the result, which will be used as input for the SPIRE flight calibration file.

I. Introduction

In this section we introduce the basic notation that will be used in the following discussion.

The resistance, R, of a NTD germanium bolometer is a function of its intrinsic temperature, T, such that:

$$R = R_o \exp(\sqrt{\Delta/T}) \qquad (1)$$

At near zero electrical power and zero optical power (dark), T is the same as the bath temperature. (Note that Δ may also sometime be referred to as T_g or T^*)

The thermal conductance of the bolometer,

$$G = G_o\,(T/.3)^{\beta} \qquad (2)$$

G_o is defined to be the thermal conductance (W/K) measured at 300 mK, also called G300. For SPIRE, the design values for R_o, Δ, G_o and β are 180 ohm, 41.8 K, 40 pW/K and 1.5, respectively.

II. The fits for bolometer parameters: R_o, Δ, G_o and β

Bolometer is a simple system. Once the design is set (ie., with designed values of R_o, Δ, G_o and β) and the device is fabricated, its resistance should be a function of just one variable: the bolometer's intrinsic temperature, T (and not the bath temperature). We extract these bolometer paramters as the following.

Since,

$$V = V_{bias}\, R/(R + R_{load}) \qquad (3)$$

The resistance of the bolometer at the bath temperature, ie., near the zero electrical power, is:

$$R = R_{load}\, V/(V_{bias} - V) \qquad (4)$$

R_o and Δ can be simply obtained using (1), with T provided by the BDA thermistors, previously calibrated by BoDAC (see Appendix A).

Notice that equation (4) can be re-written as the following,

$$R = R_{load}\, (V/V_{bias})/(1 - V/V_{bias}) \qquad (5)$$

So that at near zero electrical power, where V varies linearly with V_{bias}, we have

$$m = V/V_{bias} \qquad (6)$$

where m is the slope of the load curve at low electrical power. The slope gives the differential measurement of the voltages (V_{bias} and V), instead of their absolute values, and thus allowing us to overcome the uncertainty often associated with the true zero point or the offset in the bias or/and bolometer voltages[1].

The current thru the bolometer is simply,

$$I = V/R \qquad (7)$$

The associated electrical power, P, is then,

$$P = V^2 /R \qquad (8)$$

At equilibrium,

$$P = \int G dT = G_o/(1+\beta)(.3)^{-\beta}\, [T^{\beta+1} - T_o^{\beta+1}], \qquad (9)$$

where T is the intrinsic bolometer temperature, which may be deduced from (1), and T_o is the bath temperature. G_o and β may be extracted by fitting the data given in (8) to the model (9).

IV. The Data

We use the dark load curves data obtained during PFM5 for all five BDAs, tabulated by Tanya Lim and listed below. The properly phased-up data were obtained for the temperature range from 0.285 to above 800 mK. There are 14 different temperature points for the photometers, and 12 for the spectrometers. It is agreed that the analysis for the calibration files only contains these data with bias at the lowest frequency of 70.3 Hz, where systematic errors due to stray capacitances between bolometers and JFETs are expected to be minimal.

Here are the OBSIDs and other relevant information.

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[1] This practice, though obvious, often gets ignored and had been the source of discrepancies in the past analysis.

Table 1 – Characteristic of the data files used for the PFM5 load curve analysis

	Date	Start Time	End Time	OBSID	Bias Freq Hz	Sample Rate	PL0TEMP	SUBKTEMP	SOB temp
PHOTOMETER	28-Feb-07	20:35	21:04	300123FD	70.26	17.56	1.437	0.285	4.4
	1-Mar-07	21:29	21:57	30012421	70.26	17.56	1.432	0.299	4.409
	28-Feb-07	16:02	16:30	300123EB	70.26	17.56	1.438	0.322	4.391
	1-Mar-07	18:04	18:32	30012410	70.26	17.56	1.432	0.359	4.398
	28-Feb-07	13:24	13:52	300123DB	70.26	23.42	1.44	0.389	4.387
	6-Mar-07	10:33	11:01	300124AD	70.26	17.56	1.438	0.421	4.355
	28-Feb-07	12:03	12:31	300123DA	70.26	23.42	1.439	0.463	4.382
	1-Mar-07	20:02	20:31	30012420	70.26	17.56	1.434	0.52	4.409
	28-Feb-07	21:33	22:01	300123FE	70.26	17.56	1.441	0.577	4.396
	6-Mar-07	13:16	13:44	300124C6	70.26	17.56	1.44	0.641	4.387
	6-Mar-07	13:54	14:22	300124C7	70.26	17.56	1.439	0.648	4.382
	28-Feb-07	17:19	17:47	300123ED	70.26	17.56	1.437	0.703	4.396
	6-Mar-07	15:37	16:05	300124CC	70.26	17.56	1.438	0.799	4.389
	6-Mar-07	14:58	15:26	300124CB	70.26	17.56	1.44	0.803	4.389
SPECTROMETER	28-Feb-07	19:59	20:25	300123F6	70.26	35.13	1.437	0.285	4.617
	1-Mar-07	22:06	22:32	30012429	70.26	35.13	1.433	0.3	4.508
	28-Feb-07	15:25	15:51	300123E4	70.26	35.13	1.438	0.322	4.61
	1-Mar-07	18:46	19:13	30012418	70.26	35.13	1.434	0.357	4.57
	28-Feb-07	14:03	14:29	300123E3	70.26	35.13	1.439	0.389	4.519
	6-Mar-07	11:37	12:03	300124B8	70.26	17.56	1.438	0.421	4.597
	28-Feb-07	11:26	11:52	300123D3	70.26	35.13	1.441	0.461	4.595
	1-Mar-07	19:27	19:53	30012419	70.26	35.13	1.436	0.517	4.624
	28-Feb-07	22:17	22:43	30012406	70.26	35.13	1.442	0.575	4.61
	6-Mar-07	12:29	12:56	300124BC	70.26	17.56	1.441	0.638	4.61
	28-Feb-07	17:59	18:25	300123F5	70.26	35.13	1.438	0.704	4.578
	6-Mar-07	16:27	16:53	300124D7	70.26	17.56	1.441	0.801	4.617

The fits of G_o and beta was done using OBSID 30012429 for the spectrometers and 300123FD for the photometers. For some pixels (SL_A2, SL_C3 and SS_D3) these data sets appear to be corrupted (ie., due to incorrect handling of offset), and were replaced by 300123F6.

III. The Results

Analyses done independently by Nguyen and Woodcraft (with independent gain conversion – see Appendix B for a discussion on gain conversion) yield excellent agreement among the values of the parameter, less than a percent, for individual pixels across all BDAs (Figure 1). The values for R_o, Δ, G_o and β are tabulated in the spreadsheet. The latest version is PFM5_Calfile_v4.xls.

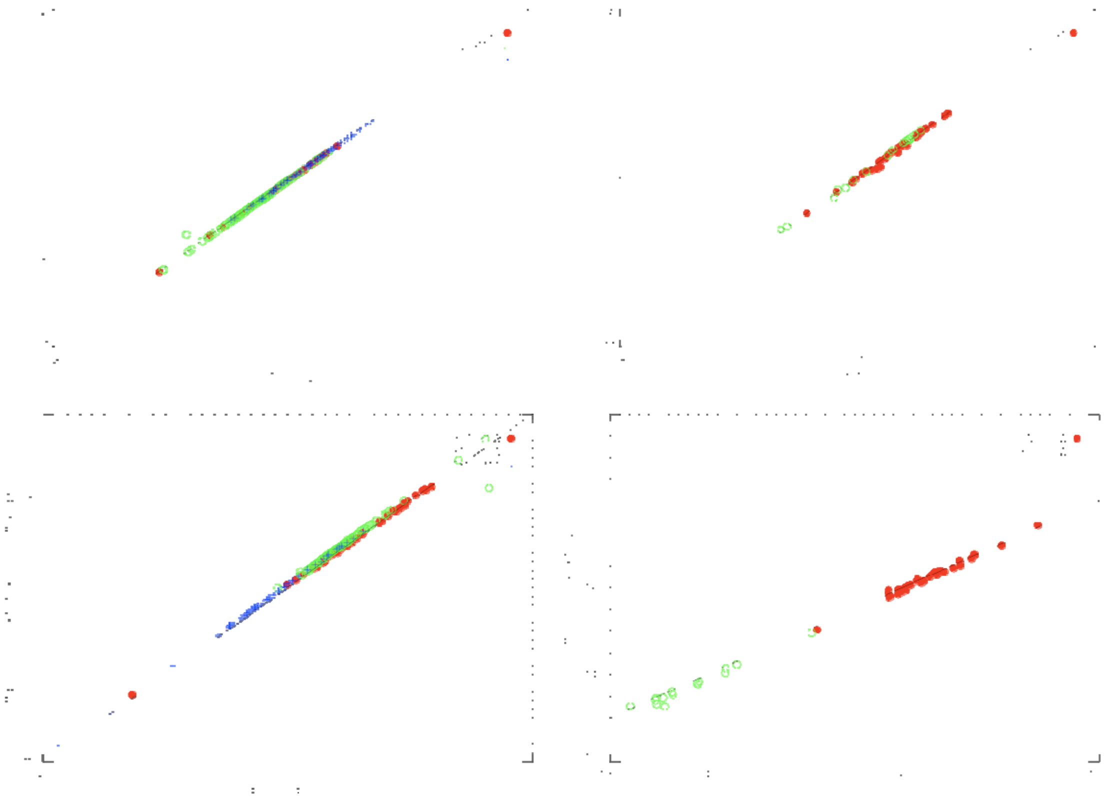

Figure 1. Comparison of values of Δ and G_o obtained independently by Nguyen and Woodcraft for the five BDAs – left are photometers and right spectrometers. The black line is the 100 percent agreement.

Note that for the channels that were not accessible (ie., due to bad cryo harness, etc.) during PFM5, we recorded values from JPL EIDP. These are marked (*) in the spreadsheet.

IV. Summary

The values of the parameters obtained from PFM5 for PLW and PSW are in reasonably good agreement (~ few percent) with those listed in the JPL EIDP, which were obtained with the JPL Bolometer Detector Assembly Cryostat or BoDAC. For the PMW, the discrepancy between PFM5 and BoDAC data is significantly larger. This was, in fact, expected since the measurements for PMW in BoDAC was done with light leakage (ie., not completely dark).

For the spectrometer units, the scatter between PFM5 and BoDAC values is much more significant. We currently do not understand the source of this discrepancy.

The RAL/JPL team have decided to adopt the bolometer parameter values obtained from the PFM5 campaign for the calibration file.

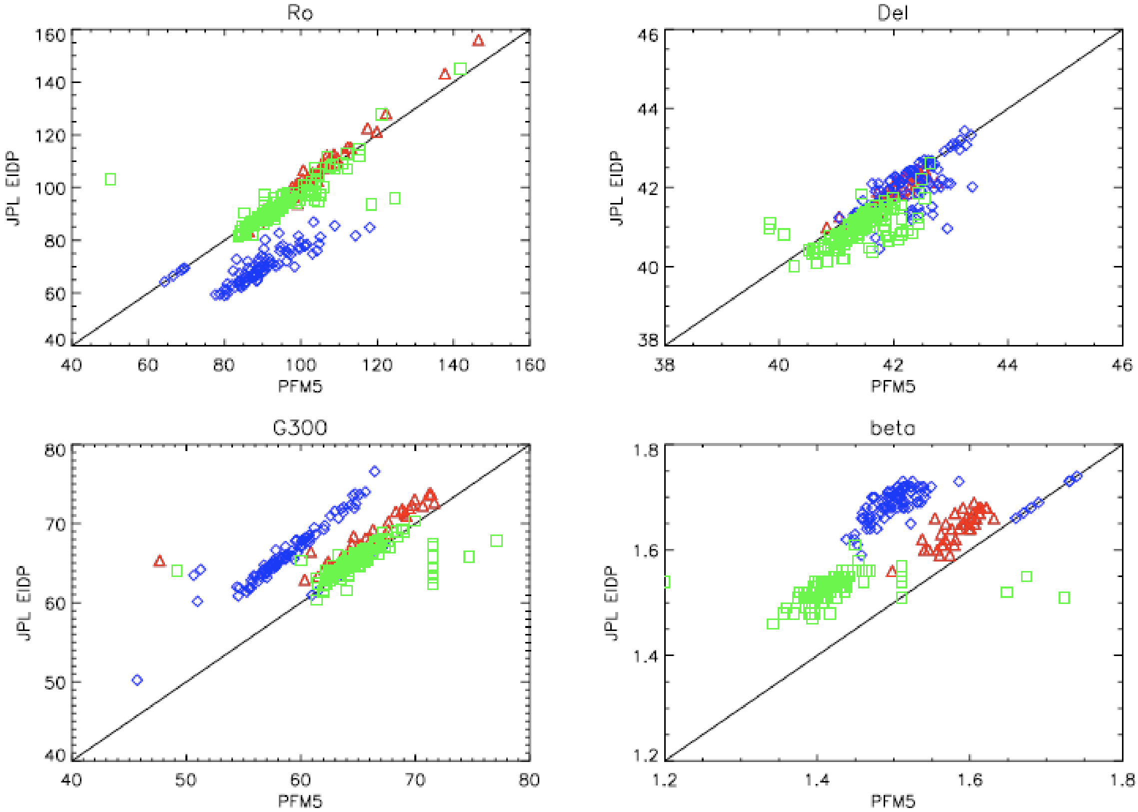

Figure 2. Values of R_o, Δ, G_o and β from JPL EIDP vs. PFM5 for the PLW (red), PMW (blue) and PSW (green). The line in black is for 100% agreement. We have good agreement in PLW and PSW. For the PMW, the BoDAC value of R_o appears to be underestimated, consistent with the fact that the measurement was done under the presence of some minimal optical power.

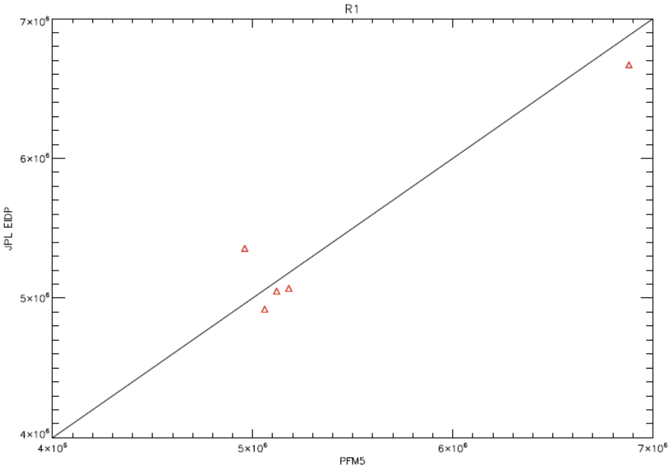

Figure 3. Value of R1 from JPL EIDP vs. PFM5 for all BDAs. The datum above the line is the PMW.

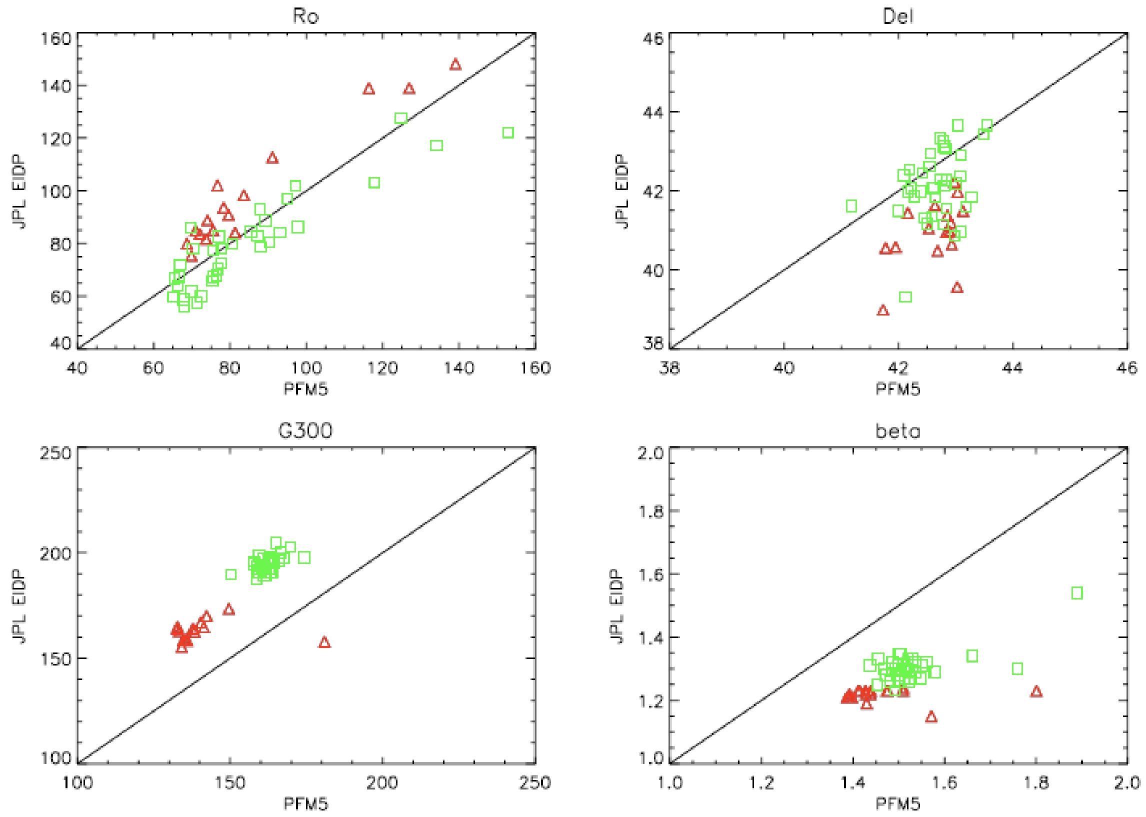

Figure 3. Values of R_o, Δ, G_o and β from JPL EIDP vs. PFM5 for the SLW (red) and SSW (green). The scatter between the two data sets appears to be significant.

References

JPL EIDP for SPIRE Detectors.

Appendix A

BoDAC Calibration of the BDA Thermistors

In calculating the bolometer parameters, it is assumed that the bath temperatures for each individual detector within the BDA are exactly the same, and the temperature value is provided by the two thermistors on the BDA. These two thermistors are permanently fixed on the array and otherwise different with the rest of the thermistors (optical and dark) in the array by two key features: 1. They are not coupled with spiderwebs - so that they are only sensitive to the bath temperature and are insensitive to incident optical power. And 2. They have much higher thermal conductance (> 10 times) to the 300mK bath.

The BDA thermistors were previously calibrated by the JPL testbed BoDAC. For each BDA (see Figure B1), the detector array is thermalized by an invar surface isolated from the 1.7K bath by means of kevlar strands. The array are cooled down to 300 mK via the (oxygen free high conductivity) copper cold finger.

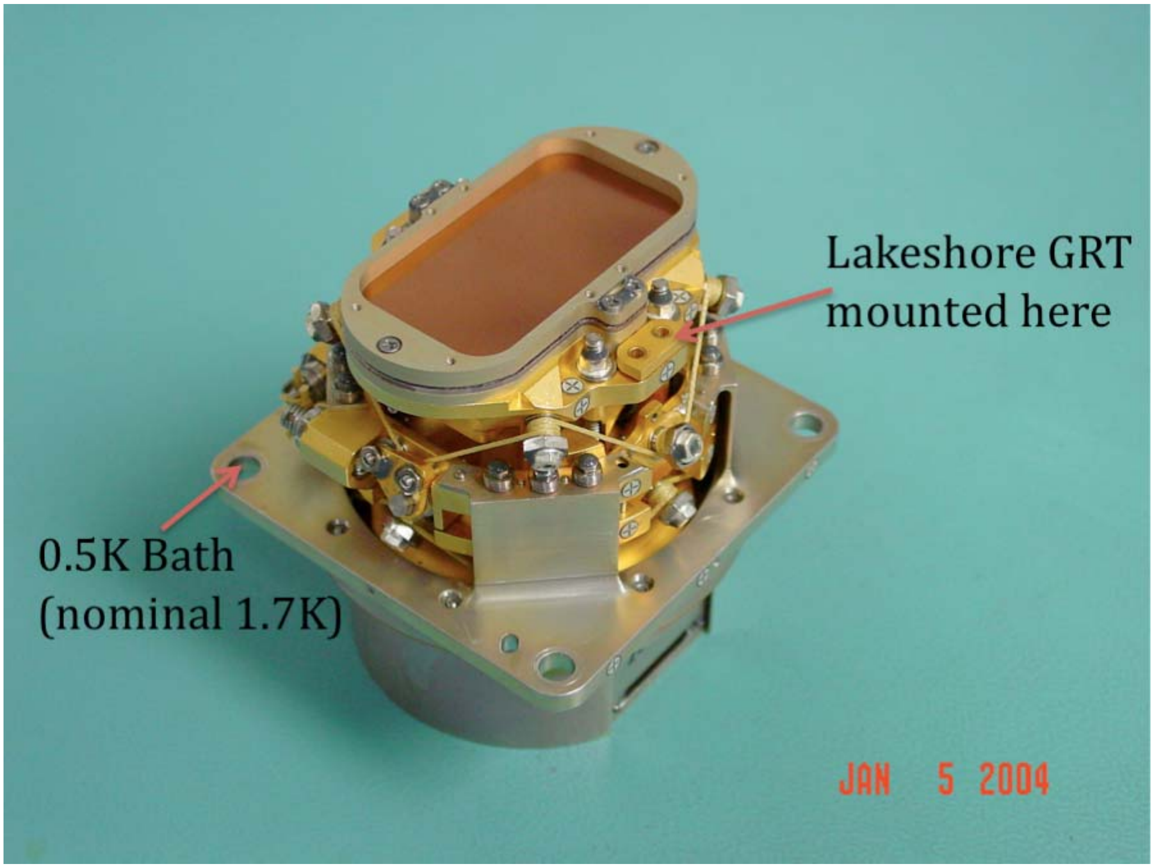

Figure B1. Under the nominal operating condition, where the warm bath temperature is at 1.7K, the temperature difference between the top of the copper thermal strap and the detector array can be as much as 10mK – this temperature gradient varies with each BDA, depends on the number of readout cables (kapton). In order to keep this gradient at a minimum, during the calibration in BoDAC setup, we set the temperature of the warm bath to be at ~.4 K via the intermediate cooling stage of the He.

The calibrations of all of the BDA thermistors were done with a *Lakeshore*® calibrated GRT (Sensor Series no. 28027, Calibration Report no. 308617, with absolute calibration rms error is 0.69 mK), which is mounted right on top of the BDA's OFHC copper cold finger. In addition, we have another thermometer mounted at the ultracold head of the sorption helium fridge. As a check, we note that the calibrated GRT was nominally about 3mK warmer than the fridge across the thermal strap.

During the calibration, the 4K bath is pumped, as a result the warm end of the BDA to below 0.5 K to minimize the temperature gradient between the GRT and the detector array. Typically, the loading on the 300mK array from 1.7K is determined to be 3 µW, results in a measured temperature gradient of about 10mK (see, for example, BoDAC EIDP). At 0.5K, the loading is roughly $\sim (0.5/1.7)^2 \times 3\mu W$ or less than 0.3 µW. So that the temperature difference between the calibrated GRT and the thermistors on the array should be less than 1mK. Note that the temperature gradient is much less than this at higher temperatures. We believe the total absolute calibration temperature error is less than a few millikelvins.

Appendix B

The Gain: Raw digital units to Volts conversion.

This part describes the conversions applied to data analyzed at IPAC andf JPL using the Bolometer Analysis Software provided by IPAC at,

https://nhscdmz1.ipac.caltech.edu/pmwiki/pmwiki.php/Spire/Software

The data is retrieved with the standalone Export Tool of the SPIRE QLA, either for the respective OBSIDs or their corresponding time interval, from the RAL data repository at http://chichester.bnsc.rl.ac.uk:8080/test_team/

The Export Tool is set up in such a way that the HK data are converted, but the science data and offset data are kept in raw format.

The data comes in FITS binary tables, where the first column represents the absolute time in GMT in seconds starting from a certain epoch. The following columns represent the bolometer voltage minus offset, or the offset voltage of one detector each, depending on file type. The order of detectors is assumed to follow the QLA order for FULL ARRAY data.

In a first step, the science data consisting of raw signals and raw offsets are converted to Volts according to:

signal = raw_signal / 71406936
offset = (raw_offset * 52428.8 – 16384) / 71406936

For spectrometer data, the signals and offsets resulting from the previous conversion are multiplied by (454./294.). We note that the correct divisor to be used should have been 71815880 and the spectrometer conversion factor should actually have been 456.6/294.56, but the difference is negligible for this purpose.

After that the matching channels of signals and offsets are coadded.

Now the bias frequency is determined from the HK parameter ‘PHOTMCLKDIV’ as

fbias = 1e7 / PHOTMCLKDIV / 512 in [Hz].

The bandpass filter gain is determined differently for photometer and spectrometer as follows:

p=complex(0, 2.0*!PI*fbias)

Photometer:

hbpf=262.8*(4.7e-3*p/(1.0+4.7e-3*p+5.85e-7*p^2))
gain_bandpass=sqrt(hbpf*conj(hbpf))/262.8

Spectrometer:

hbpf=114.4*(4.7e-3*p/(1.0+4.7e-3*p+3.14e-7*p^2))
gain_bandpass=sqrt(hbpf*conj(hbpf))/114.4

All bolometer voltages are divided by the resulting bandpass gain and the nominal gain of 0.96 for the JFET stage. The results are written to a new binary FITS file that has the same structure as the input file.

The relevant IDL procedures are the following: bolo_corr_gain.pro,
bolo_qlafile_convert.pro, bolo_add_offsets.pro and bolo_qla_sigconv.pro

The procedure described above provides the nominal corrections for frequency independent amplification factors in the electronics chain, the frequency independent amplification of the JFETs and the frequency dependent amplification factors of the bandpass. No corrections are applied for RC roll-off between bolometers and JFETs nor any corrections due to misadjusted phase of the LIA.

PFM5 Calibration File -